Climate, Growth and Drought Threat to Colorado River Water Supply

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I. Introduction

Abstract

With climate change looming, continued population growth, and the recurrence of multi-year droughts, the future reliability of Colorado River water supply is in question. We assess the risk to Colorado River water supply for the next 50 years (2008-2057). Under current practices, and in the assumed absence of climate change, we find a 5% risk of reservoir depletion through 2026 increasing to 9% by 2057, demonstrating resilience to demand growth and natural climate variability. Assuming a 20% reduction in Colorado River average flow due to climate change by 2057, increases risk through 2026 to less than 12%, but greatly increases risk to 52% in 2057. However, **we find management alternatives can greatly reduce risk** – under aggressive management the risk reduces to 32%. A lower rate of climate change induced flow reduction, demand adaptation and aggressive management can further reduce the risk to around 10% - suggesting substantial flexibility in existing management could mitigate the increased risk.

Basin Facts

- 16.5 million acre-feet (MaF) **allocated** annually
- 15 MaF average annual **natural flow** into Lake Powell over past 101 years
- High year-to-year flow variability (**Fig. 2**)
- 13 to14.5 MaF **consumptive use** annually
- 60 MaF storage throughout basin
- 50 MaF storage between Lakes Powell and Mead
- Decisions governed by Law of the River

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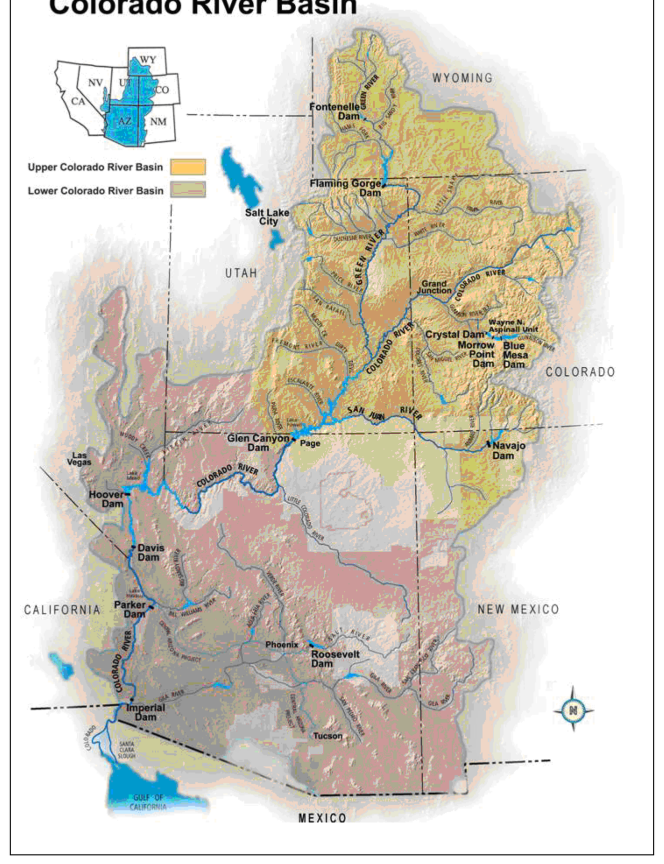
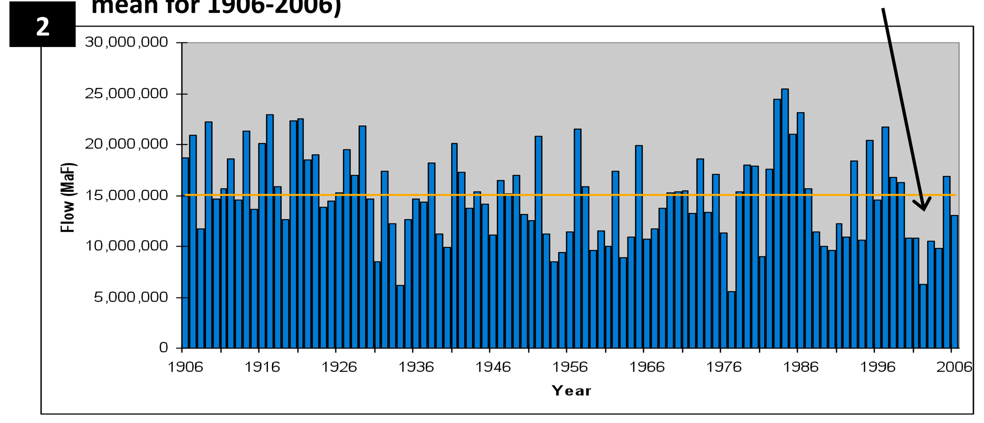


2 Annual natural flow at Lees Ferry, AZ (horizontal line is mean for 1906-2006)



Motivation

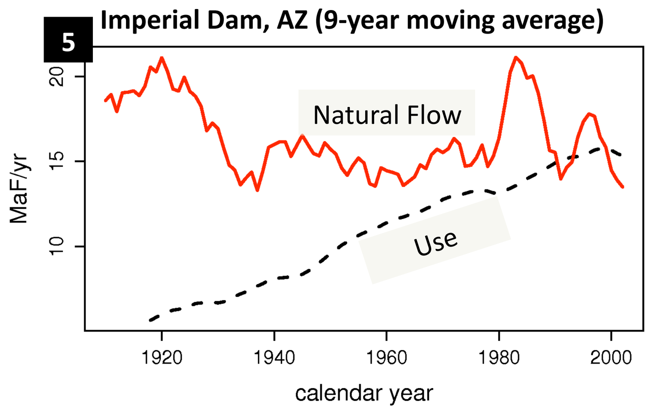
- Recent drought most severe observed event (**2**).
- Strain on Lakes Powell and Mead storage (**3**).
- Projected climate change induced reductions in flow (**4**).
- Growing basin demand (**5**).

3 Lake Powell at confluence with Dirty Devil River (USGS)

4 Recent studies project reductions Colorado River flow by mid-21st century (Ray, et al., 2008)

Study	GCMs (runs)	Spatial Scale	Temperature	Precipitation	Year	Runoff (Flow)
Christensen et al. 2004	1 (3)	VIC model grid (~8 mi)	+3.1°F	-6%	2040–69	-18%
Milly 2005, replotted by P.C.D. Milly	12 (24) (~100–300 mi)	GCM grids —	—		2041–60	-10 to -20% 96% model agreement
Hoerling and Eischeid 2006	18 (42)	NCDC Climate Division	+5.0°F	~0%	2035–60	-45%
Christensen and Lettenmaier 2007	11 (22)	VIC model grid (~8 mi)	+4.5°F (+1.8 to +5.0)	-1% (-21% to +13%)	2040–69	-6% (-40% to +18%)
Seager et al. 2007*	19 (49)	GCM grids (~100–300 mi)	—	—	2050	-16% (-8% to -25%)
McCabe and Wolock 2008	—	USGS HUC8 units (~25–65 mi)	Assumed +3.6°F	0%	—	-17 %
Barnett and Pierce 2008*	—	—	—	—	2057	Assumed -10% to -30%

5 Colorado River use[1] and natural flow above Imperial Dam, AZ (9-year moving average)



[1]Total consumptive use in the Lower and Upper Basins, including major reservoir evaporation, bypasses to Cienega de Santa Clara and losses from native vegetation. Deliveries to Mexico assumed to be 1.5 MaF.

II. Model Development and Data

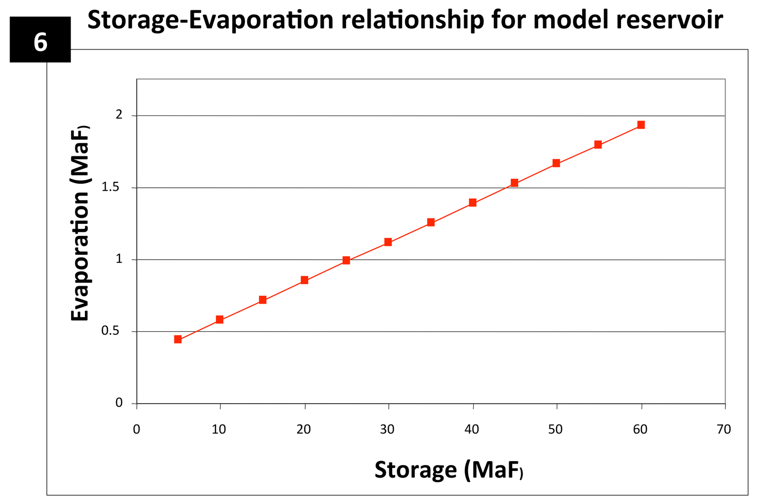
Model

- Simple water balance model:

Change in Storage = Inflow – Outflow

- **Inflow** is the sum of flow at Lees Ferry, AZ and the Lower Basin intervening flow
- The live storage capacity is 60 MaF, and is modeled as a single reservoir
- **Outflow** includes the deliveries to Upper and Lower Basins, Mexico, transmission losses in the Lower Basin and reservoir evaporation (**Fig. 6**)
- The initial reservoir storage is 30 MaF (50% of capacity)
- Lower Basin and Mexico deliveries are assumed constant, while Upper Basin demand follows the depletion schedule in **Fig 9.**

6 Storage-Evaporation relationship for model reservoir



Policy and Growth Alternatives

A. The **interim shortage policies** (Interior, 2007) employed with **full demand growth**

B. Same as A, but with **larger delivery shortages ("Interim Plus")**

C. Same as B, but with a **50% reduced upper basin demand growth**

D. Same as C, but with **full initial storage**

E. Same as C, but with **new threshold policy** post-2026

8 Details of shortage policies considered

Interim Policy		Interim Plus Policy		New Threshold Policy	
Res. Storage (%)	Shortage (KaF)	Res. Storage (%)	Shortage (% of current demand)	Res. Storage (%)	Shortage (% of current demand)
36	333 (2.5%)*	36	5	50	5
30	417 (3.1%)*	30	6	40	6
23	500 (3.7%)*	23	7	30	7
				20	8

***Note:** Percentages are based on 2008 demand of 13.5 MaF

Stochastic Flow Data

- Markov (NHM) method of Prairie et al. (2008) method combines the paleoclimate record with historical natural flow.
- Capable of generating longer wet and dry sequences than seen in the historical record.
- Intervening flow between Lakes Powell and Mead also generated stochastically.
- Ensemble of 10,000 fifty-year streamflow sequences generated, capturing natural climate variability.

Metrics and Definitions

- Risk of drying is computed for each policy/ flow-reduction scenario.
- Drying is defined as depletion of live storage on the whole system.
- Risk is computed as the probability of drying in any given year.
- Distribution of water deficit events also calculated.
- A deficit occurs any time the full demand is not met. This can be due to physical constraints (i.e., no water available) or shortage policy.

Climate Change Projections

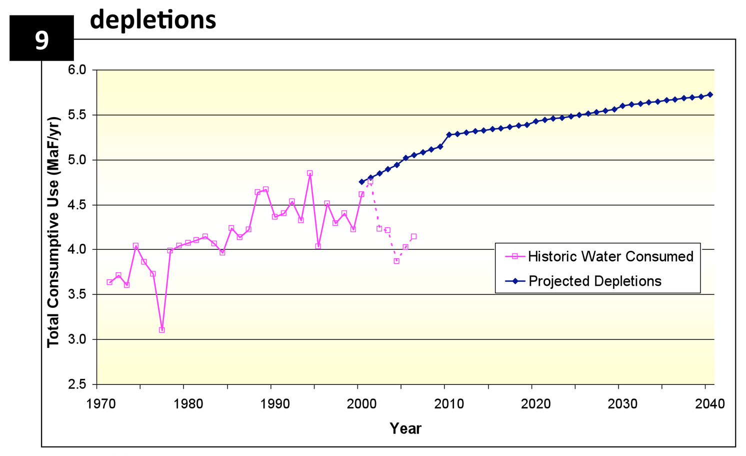
- Assumed percentage reduction applied to the stochastically generated flows.
- Reduction ramps up from zero in 2008 to their full value in 2057 (**Fig. 7**).
- **0%, 10% and 20% reduction scenarios** were chosen to span the range of most current studies (**Fig. 4**)

7 Climate change scenarios investigated

Scenario	Annual Flow Reduction	Mean Flow in 2057
Natural Variability	0 KaF/yr	15 MaF
10% Mean Flow Reduction	30 KaF/yr	13.5 MaF
20% Mean Flow Reduction	60 KaF/yr	12 MaF

Note: Thousand acre-ft per year (KaF/yr)

9 Upper basin historic consumptive use and projected depletions



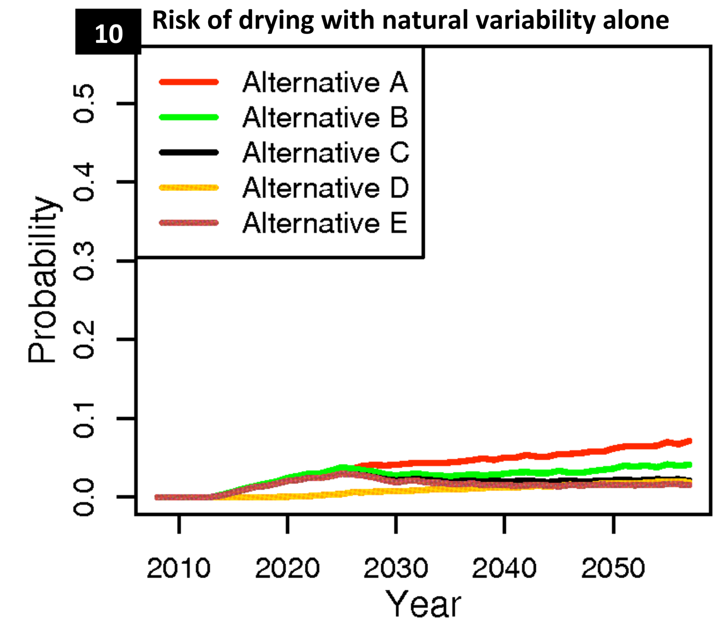
Notes: (1) Dashed portion is based on provisional data
(2) Consumptive use includes CRSP reservoir evaporation

Current Upper Basin water use is approximately 800 KaF/yr less than projected in the Interim Guidelines EIS (Interior, 2007, 2008) (**Fig. 9**).

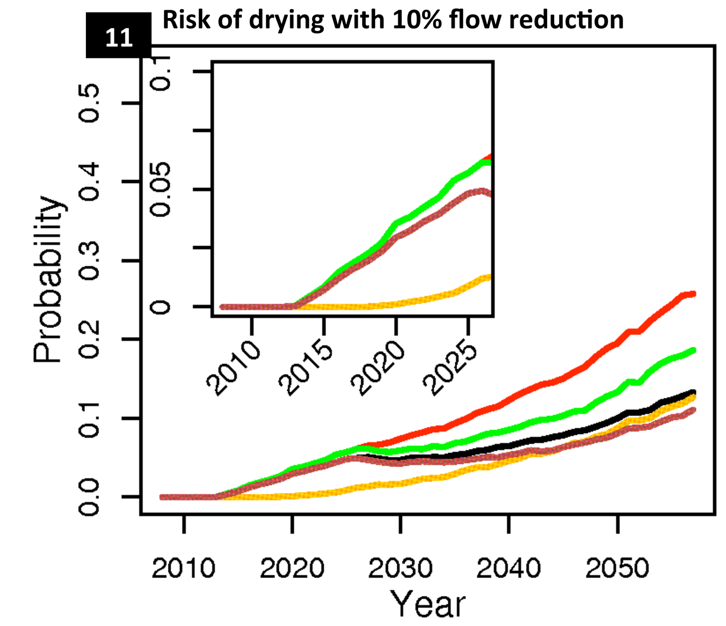
3.7 MaF/yr (12.7 MaF basin total) used as "starting point" in alternative set of simulations to bracket low end of demand-induced risk (**Fig. 13**)

III. Results and Conclusions

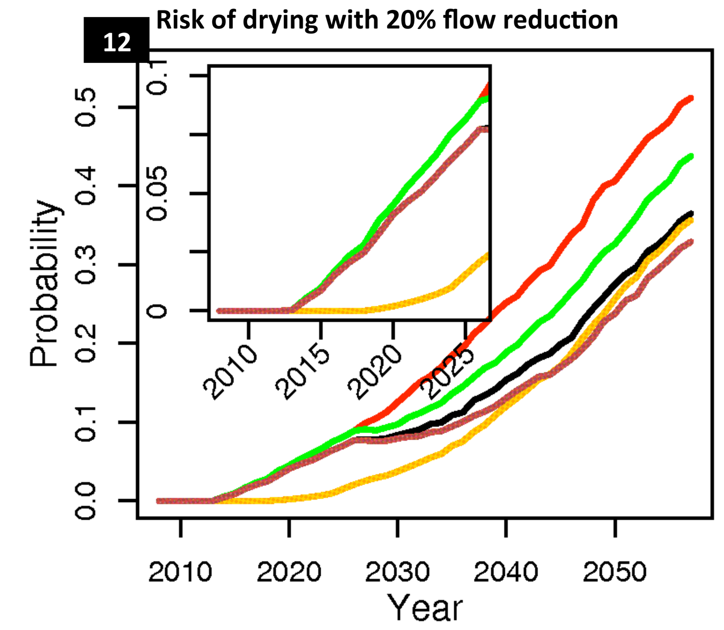
10 Risk of drying with natural variability alone



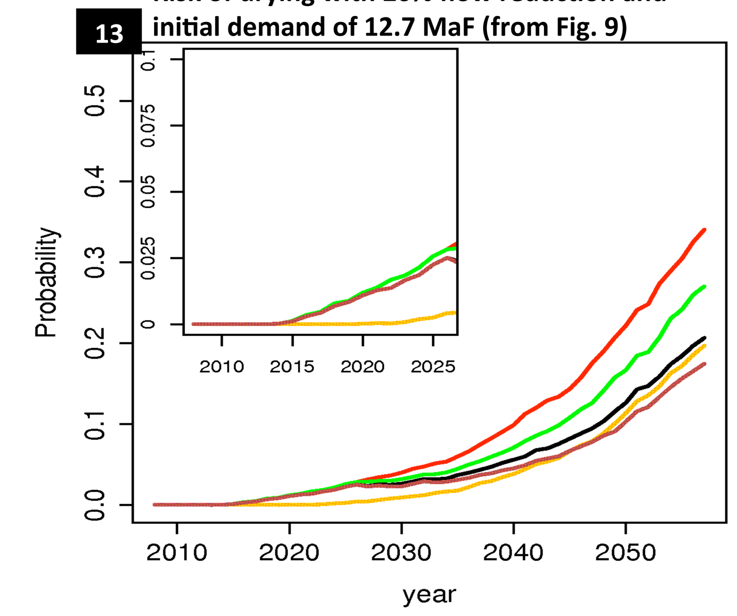
11 Risk of drying with 10% flow reduction



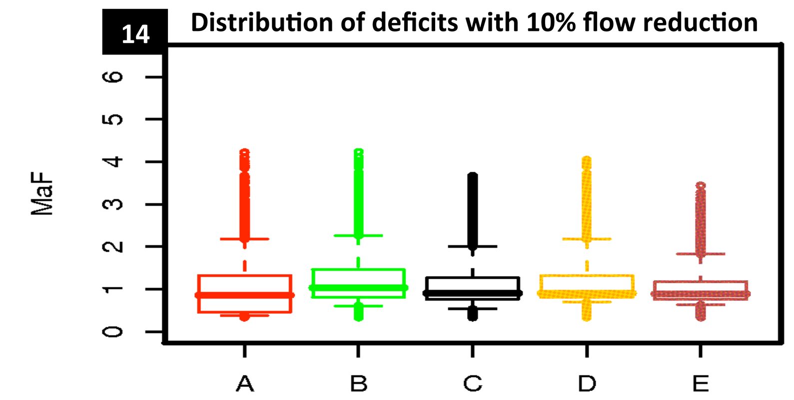
12 Risk of drying with 20% flow reduction



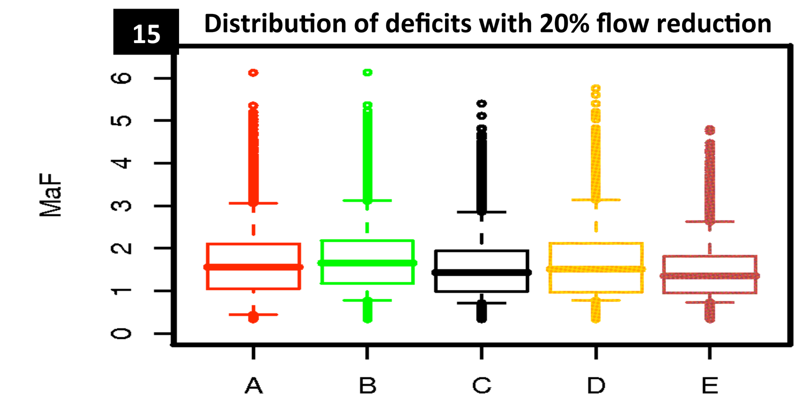
13 Risk of drying with 20% flow reduction and initial demand of 12.7 MaF (from Fig. 9)



14 Distribution of deficits with 10% flow reduction



15 Distribution of deficits with 20% flow reduction



Key Results

(I) Near-term risk of drying for all scenarios is relatively low, however **after 2026 risk increases dramatically.**

(II) Figures 11 and 12 show that **combinations of aggressive shortage policy and slowed growth can mitigate risk** of drying by as much as 35% (for 20% flow reduction) and 66% (for 10% flow reduction).

(III) More aggressive shortage policy (Alternative F) can reduce the median shortage volume, which may be desirable.

(IV) Modeling initial demand as reported consumptive use (**Fig. 13**) and according to the depletion schedule (**Fig. 12**) provides an "envelope" within which the actual system state most likely falls.

(V) The interim period of relatively low risk should be used to devise robust water management that can reduce system risk post-2026.

References

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Ray, A. J., et al. (2008), Climate Change in Colorado; A Synthesis to Support Water Resources Management and Adaptation, CU-NOAA Western Water Assessment, Boulder, CO.

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U.S. Department of the Interior. (2007), Final Environmental Impact Statement Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead, Bureau of Reclamation, Boulder City, NV.

RECLAMATION
Managing Water in the West